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LNG storage tanks: advancements in weld inspections

New inspection method improves jobsite examinations and verification of welds

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The international liquefied natural gas (LNG) industry continues to grow, and moves stranded natural gas (NG) from countries that have surplus supply to expanding markets. In order to fulfill global demand, the number of facilities being built to export, ship and import LNG has also increased tremendously. LNG storage tanks (Fig. 1) play a prominent role in this process and are typically on the critical path for constructing LNG terminal projects.

Three LNG storage tank designs are available and selections are made based on specific project needs: single, double and full containment tanks. All three are designed to store LNG safely and contain any spills in the unlikely event of a leak in the primary liquid container. Due to the stored fuel's nature, all three tank types are designed with an inner and outer wall separated by insulation materials. The inner wall must be designed for LNG's cryogenic temperature (–260°F). The material used most extensively is 9% nickel steel as the material remains ductile at cryogenic temperatures.

To construct the inner liquid containing tank, large plates of 9% nickel steel are welded together (Fig. 2). Welding procedures require using appropriate weld filler to achieve the required mechanical properties and toughness. Applicable design codes and standards govern the nondestructive examination (NDE) techniques required to ensure that welds are acceptable.

Radiography vs. ultrasonic technologies. Traditionally, full fusion welds on LNG storage tanks have been inspected using radiographic examination (RT). Technicians take weld radiographs using either x-ray or gamma ray sources, develop the film and then review it to determine if the weld is acceptable. RT is known for its sensitivity to volumetric flows and clearly identifies slag and porosity flaws that indicate a problem in either the weld itself or welding procedure.

Ultrasonic examination (UT) has been used primarily to inspect welds on structures made of carbon or low alloy steels (ferritic metal). Because 9% nickel steel filler metals are a high nickel alloy, its structure is austenitic rather than ferritic. Austenitic materials produce a weld deposit that has a coarse, grainy elongated (dendritic) structure. This tends to scatter sound waves, thus causing distortions and interference with results.

Furthermore, considerable equipment costs, high skill level of technicians, and lack of integrated systems performing the procedures has made using UT for LNG storage tank weld inspections rare. However, recent technological advances have leveled the playing field between UT and RT technologies. As a result, UT has emerged as an inspection method equally well-suited for jobsite examination and, in some cases, it provides a better alternative.

Austenitic weld examinations. Recent developments in ultrasonic technology have made it practical to develop an examination methodology designed specifically for austenitic welds. This process combines multiple UT techniques to effectively examine the weld joint and detect detrimental flaws within it.

Commercial UT hardware and software has become more sophisticated in its ability to handle multiple transducers and to process and display data. For ultrasonic ferritic weld inspection, transducer arrays have been mounted on rolling carts tied to computerized data collection systems. This same concept was applied in developing a system for austenitic welds. However, highly specialized transducers are carefully selected and assembled on the carriage.

The required specialized transducers are determined from weld schematics. Production weld mock-ups are mandatory to determine appropriate gain settings and to confirm adequate coverage. Transducers are then mounted to a carriage and are ready for the inspection process. A pump is included on the apparatus to constantly spray water onto the examination surface, ensuring that high-frequency sound waves are successfully transferred.

Semi-automatic UT examination system. A recent development in methodology and apparatus combines technology advancements into a single process designed specifically for UT inspection of austenitic weld joints. The semi-automated

FIG. 1 Typical storage tank for LNG at a terminal site.

apparatus, which has been patented in the US as well as a number of other countries, includes hardware (transducers, carriage, computer equipment, etc.) and software systems needed to perform examinations and capture the results in the field. It is automatic in that the computer software captures ultrasonic data as it examines the weld joint while the carriage is moving along the weld seam.

The computer is monitored as data is collected, ensuring the system is functioning correctly. The operator, who is a qualified Level II UT NDE technician, can also screen data as it is being collected—thus, proactively addressing any welding problems detected immediately, rather than waiting for final reports to be reviewed.

Computer hardware, which has become smaller and more portable, is incorporated into the system and can be used easily in the field without cumbersome restrictions. Operator training for the equipment and procedures is provided in a laboratory environment utilizing tank mock-ups. The equipment is then transported to the construction site and put into production.

UT benefits for LNG storage tanks. There are a number of advantages in using UT to inspect 9% nickel steel weld joints for LNG storage tanks. These include safety considerations, quality factors, time and cost savings, and space allocations (Table 1).

Safety considerations. Safety is the primary consideration on every LNG project. By eliminating radiation usage in the NDE process, UT inspections remove radiation hazards as a safety concern.

The UT process also eliminates the need to handle and dispose of chemicals associated with RT technology. Another important safety consideration is the elimination of the NDE operators working during off-hours to perform inspections. Isolating inspectors to perform RT examinations is necessary to protect other workers in the area, which poses risks for those performing the examinations.

Quality factors. While RT is normally better at detecting three-dimensional volumetric flaws, such as slag and porosity, UT is normally better at detecting two-dimensional planar flaws, such as cracks and non-fusion occurrences. In welding, these two-dimensional flaws are those that cause the greatest concern. Detecting and correcting detrimental two-dimensional flaws is essential to ensuring the LNG storage tank structure integrity.

TABLE 1. RT vs. UT nondestructive examination

Item	RT	Semi-automated UT with computer-based data acquisition methods
Sensitivity for volumetric flaws (slag and porosity)	Strength	Moderate to high
Sensitivity for planar flaws (cracks and non-fusion)	Moderate	High
Provide permanent record (baseline)	Yes	Yes
Multiple copies of results	No	Yes
Data on flaw length	Yes	Yes
Data on flaw depth (ferritic material)	No	Yes
Data on flaw depth (austenitic material)	No	Yes, within limits
Thin material	No limitation	Limited to 9 mm
Safety	Isotope/radiation hazard	No hazard
Schedule	Work restricted to nonproduction work time unless heavy shielding	Work can be done in unison with production work
Operator skill level	Moderate	High
Acceptance basis	Workmanship	Fracture mechanics
API approved	Yes	Yes

For RT examinations, acceptance criteria are based on consensus standards, which inspectors are trained to read. For UT examinations, engineering calculations derived from fracture mechanics are used to set the acceptance standard. This provides for a much more precise methodology for interpreting results and providing a sound structure.

Other ways that UT contributes to the inspection quality process is by providing a permanent electronic examination record that can be easily copied or transmitted. Thus, test results can be displayed and analyzed on a computer monitor.

The UT test output is more consistent than a corresponding RT examination. Output quality with RT, like other photographic techniques, can vary depending on the time the shot is taken, film placement, chemical quality used in film processing and film development techniques. UT provides a consistent view that is not dependent on these variations. Furthermore, the semi-automated UT examination system, with its advanced data acquisition systems, places less reliance on the individual technician's skill since other trained inspectors can easily review records.

Time and cost savings. UT inspections can provide time and cost savings that can be significant over the course of a project. The UT procedure is a linear scanning process, as opposed to raster scan techniques employed in manual procedures. The process allows both sides of the weld to be examined at the same time. Once welding is completed and cooled, UT inspection can follow behind the welders and inspect joints immediately. The inspection time for the UT process is less than that spent performing RT examination.

In contrast, RT examinations cannot occur during production hours unless shielding or distance is provided which allows workers in the area to work safely. Normally, a second shift comes in at night or on weekends to take radiographs. The film must then be developed and results analyzed. This can cause considerable delay in resolving any identified weld issues. RT also constrains the contractor when faced with adding extra shifts because time is already devoted to taking weld radiographs.

With UT, there is no delay; the results can be viewed and immediate action taken if necessary. While UT equipment is more expensive to purchase, the time savings and schedule improvements may well offset the higher equipment costs.

Space allocations. Less area is needed to store the UT inspection results than that needed for storing radiographs produced by RT examinations. Once RT film is developed, it must be stored onsite for reference. UT results must also be stored. However, since the data is captured electronically, the results can be downloaded onto a CD or computer. From there, the results are reviewed for a final report and can be easily stored, backed up and transmitted from a desktop computer.

Testing and implementing UT inspections. After developing the semi-automatic UT methodology and equipment, the new procedure was tested extensively in a welding laboratory. Third-party process validation was sought, as well as API acceptance of UT in lieu of RT based on fracture mechanics criteria.

An independent third party has validated the procedure and the API Standards Committee has approved using UT in lieu of RT based on fracture mechanics acceptance criteria. UT will be permitted as an alternative to RT in Appendix U of Addendum 1, API 620 Tenth edition (publication pending).

Moving forward. As LNG projects proliferate globally, new construction technologies are emerging that will help make these projects safer, technically superior and more cost-effective to build. Companies continue to develop and evolve these technologies, bringing them to the field as soon as they are adequately tested and approved for use.

FIG. 2 Technician welding steel plates together for a component of an LNG storage tank.

The development of a patented UT methodology and apparatus to inspect austenitic welds for LNG storage tanks is one example of how research, creativity and experience can help improve safety, shorten the work schedule and produce a higher-quality examination process for LNG projects in the field. **HP**

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